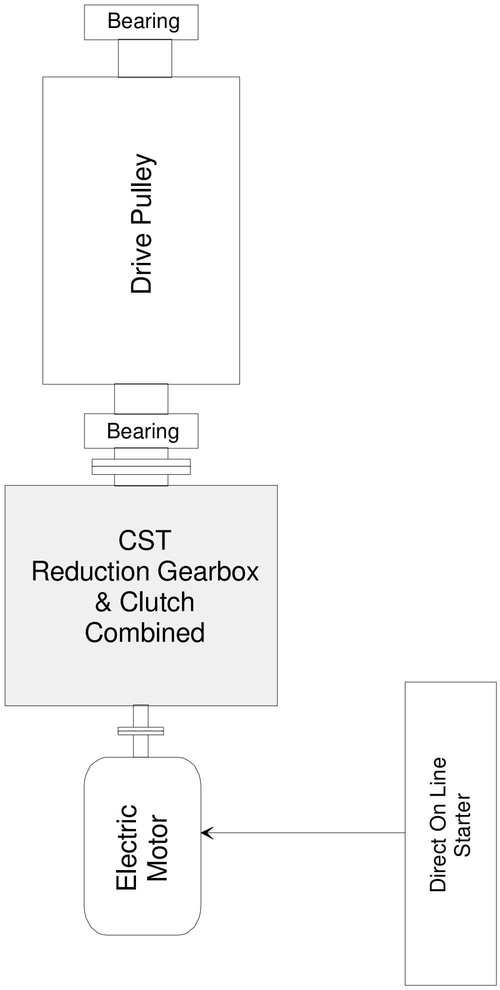
1.1. *Tension Control in Conveyors*

Belt tension is a critical component in conveyor design. It limits the amount of load that a conveyor can carry and is important in transferring the power from the driving force into the belt via friction. For any particular conveyor, there will be a certain amount of power required to move its load. The power is developed by an electric motor and then transferred to the conveyor belting via gearboxes and drive pulleys. On longer conveyors, soft starting devices are included such as clutches, fluid couplings or variable motor speed drive controls. Soft starts are essential in reducing the maximum tension seen in the conveyor belt. High tensions produce strain on the weakest part of a belt which is usually the belt joins. (clips and/or splices)

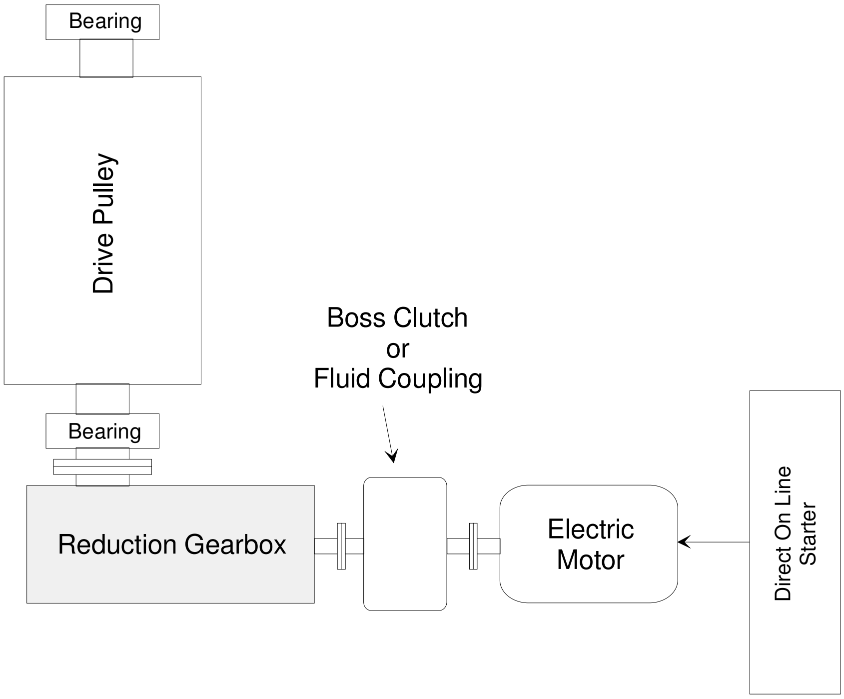
Below is an example showing how a CST is configured to drive a conveyor pulley.



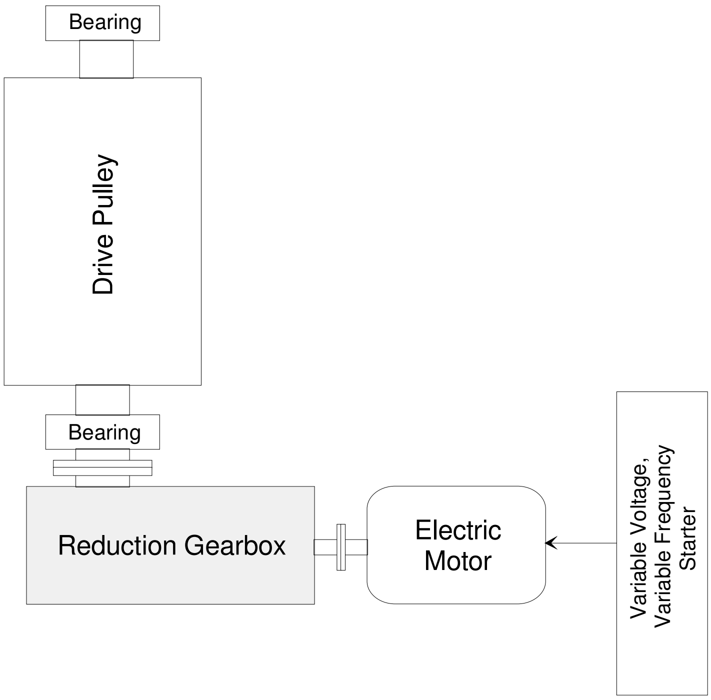
A CST drive combines a reduction gearbox with a slow speed wet clutch on its output shaft. It has the advantage of being able to accurately control torque at low speed and all the way through the acceleration ramp to full speed. When multiple drive pulleys are installed on the drive head, a drive pulley with a slightly larger diameter can be slipped to maintain power sharing between the multiple electric motors.
A DOL starter provides unloaded motor starts and allows the use of any voltage configuration for the motor.

The ability to tolerate low amounts of slip indefinitely also makes them ideal for tripper driving.

Below is an example showing how boss clutches and fluid drives are configured to drive a conveyor pulley. The torque control is on the high speed side of the gearbox.



Below is an example showing how variable speed drives are configured to drive a conveyor pulley. Variable speed is provided directly by the electric motor.



Power Transfer from Drive Pulley to Conveyor Belting

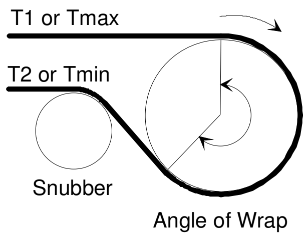
Power transfer from the drive pulley to the conveyor belting is dependent on friction. Insufficient friction results in belt slip. Belt slip creates belt and pulley lagging damage and can generate sufficient heat to be a fire risk. The amount of friction between the pulley and the belting is influenced by the following factors :-

1. Angle of wrap.
2. Maximum tension to be transmitted.
3. Face pressure between belting and drive pulley.
4. Pulley lagging and belt hardness.
5. Environmental conditions.

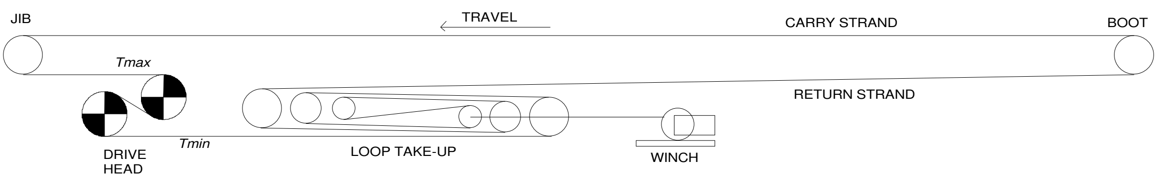
Angle of Wrap is decided during the conveyor design process and is the angle that the belting is in contact with the drive pulley. Of note is that the relationship between friction and the angle of wrap, is based on the natural logarithm (e = 2.718).

Friction ~ e^{θ} θ = wrap angle in radians 2π radians = 360^{o}

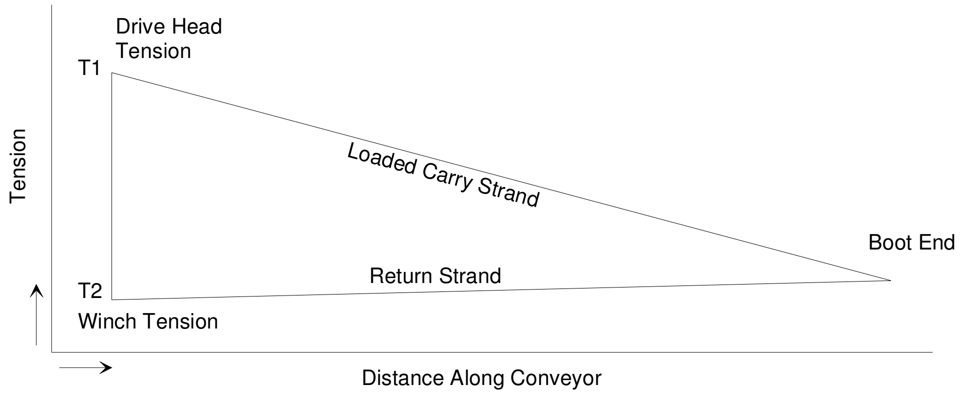
This means that an increase in wrap angle gives a logarithmic increase in friction. Designers use pulley configurations that provide the maximum angle of wrap.



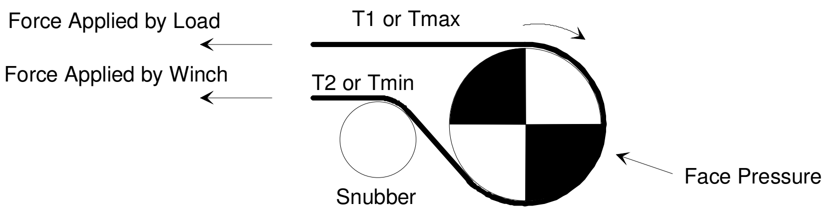
Maximum Tension to be transmitted is also referred to as "T1" or "Tmax". This value is decided during the design phase and limited by the selected belting, the belting joint method and the safety factor that the conveyor designer is prepared to operate with. Belt clips de-rate the breaking strain of a conveyor to approximately 1/3 of its nominal value. Safety factors of eight times are typically used in design. The maximum tension in the belt exists on the pulling side of the first drive pulley in the carry strand. On a fully loaded conveyor, this tension is then dissipated along the carry strand until the boot roller is reached. There is a further small drop in tension along the return strand back to the tensioning winch or weight tower where the minimum tension in the conveyor is held. This point is also referred to as T2.



The following chart is used to indicate typical tensions around a conveyor. Note this is a simplistic model with a uniform load and uniform gradient.



Face Pressure between belting and drive pulley is the result of two forces and the surface area in contact between the belt and the pulley. The two forces are T1 and T2 tensions. T1 is the back force from the load against the drive pulley, while T2 is provided by the winch.



The primary task of the winch is to maintain a constant T2 tension under all circumstances.

The value of T2 is nominated by the conveyor designer after taking all the components of friction into consideration during the design process.

Although belting appears stiff, it has a component of stretch when under load. The amount of stretch depends on the material and structure of the belt, but values of 1% are common and belts with up to 4% stretch have been manufactured. On a short conveyor, this amount is insignificant, but on a long conveyor (>1km), this stretch requires considerable movement of the winch during starting and as load comes on and off the conveyor. This is necessary to maintain the constant T2 tension. The winch is continually reeling in and out to compensate for the changing stretch in the belt. A 1 % stretch in a 4km conveyor will average out to approximately 20 meters of length change from running fully loaded to a stationary conveyor.

The stretch in the carry strand also means that the drive head travels slightly faster than the boot end. If the drive head is travelling at a constant speed and the boot speed is changing, then the speed variation is due to elastic stretch and contraction in the carry strand.

Pulley Lagging & Belt Hardness is a function of the design process and is a major component of friction. Lagging material, grooving patterns and belt hardness all contribute to friction values. It is important to keep in mind that this function never improves but will degrade with wear and environmental conditions. The wear comes from the belt changing from high tension to low tension around the pulley. The tension is decreasing as it travels around the pulley and therefore releasing the stretch put into it by the higher tensions in the carry strand. This phenomenon is known as creep. As the stretch is released at the lower tensions, the belt longitudinal value is shrinking back against the travel of the lagging. Over long periods, the small backward motion over the pulley lagging causes wear.

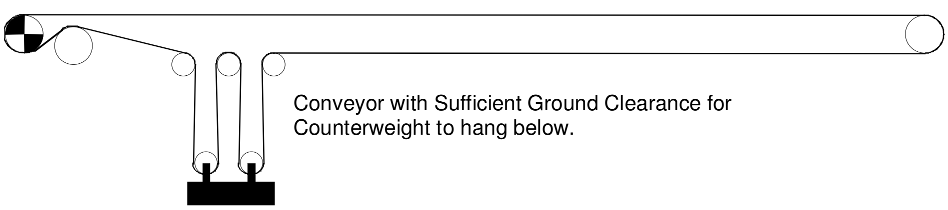
Environmental Conditions such as water, clays and coal fines sitting between the belt and the drive pulley lagging can significantly lower friction and lead to belt slip. It is important that belt cleaning devices, such as scrapers and wash rollers, are maintained. Also ensure that the de-dust water sprays provide a de-dusting mist and not just pour water all over the drive head.

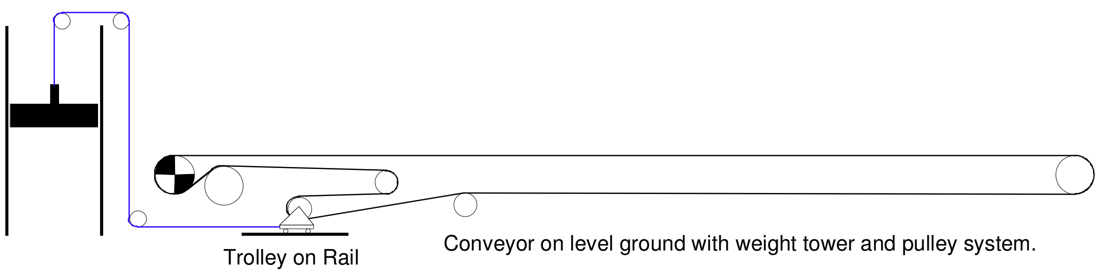
1.2. *Vector Drive Operation*

Vector drives are variable frequency drives with additional feedback that allow an accurate determination of motor magnetising current and motor torque producing current.
In principle, the current that flows in a motor has two components. One is the magnetising current which is used to create the rotating magnetic field (flux) that is used to cut the rotor bars. This current magnetically connects the stator to the rotor and lags the applied voltage by 90 degrees. The second is the torque current. The torque current provides the rotating force in the rotor is in phase with the applied voltage. Knowing the phase relationship between voltage and current, it is possible to calculate the amount of torque being produced by the motor for a particular current.
The vector drive also uses a motor look up table that accurately predicts the torque from the motor, based on close measurement of the slip of the motor and using look up tables. Percentage slip versus torque curves are provided by motor manufacturers. To measure slip, an encoder is attached to the rotor of the motor and the drive calculates the difference between its output frequency (synchronous output speed) and the feedback speed from the encoder.
In practice most manufacturers now offer open loop (VVVF control) or close loop (vector control) as standard in their drives.
For a more detailed explanation see the vector drive link to Reliance Drives in relative web information at the start of this document.
The advantage of a vector drive is that it can maintain full motor torque at zero speed in a standard induction motor. This makes it suitable for use as a winch to tension conveyors. (Full torque at zero speed was previously the domain of servo motors.)
Although vector drives operate with normal induction motors, they may spend considerable time running at slow speeds. This prevents the normal cooling fan on the induction motor being effective. It is typical to have a separate electric fan attached to the motor if it is to run at stall or low speeds for any period of time to ensure adequate cooling of the motor. The fan will be driven from its own contactor and not connected to the motor supply.

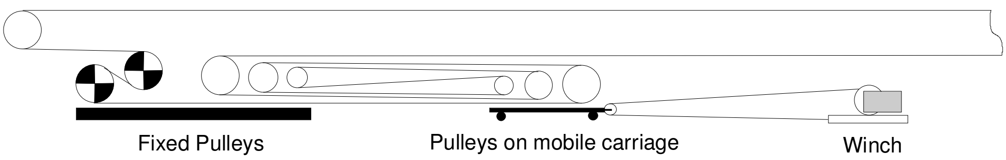
1.3. *Winch & Loop Take Ups versus Gravity Towers*

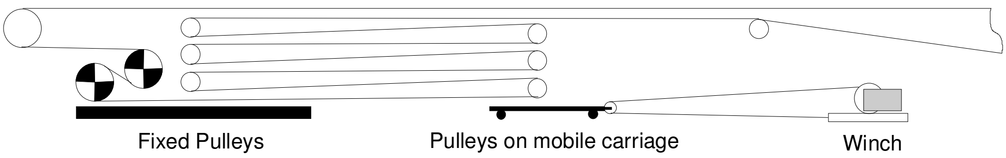
The most common method to provide tension control on long conveyors is the gravity tower. Examples below





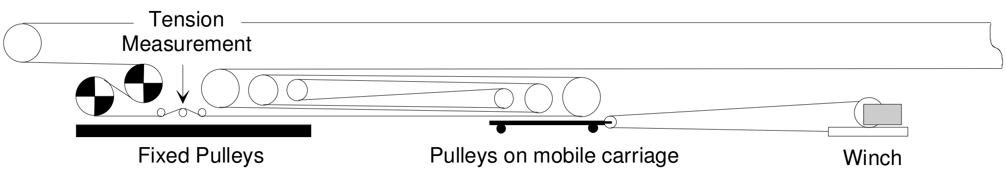
A conveyor cannot stretch any faster than is its acceleration rate. A typical conveyor accelerating to 5 ms in a 60 second period, gives a 0.08 $msec^2$ acceleration rate. The counterweight, with gravity acting, is capable of 9.8 $msec^2$ of acceleration. The weight of the counter weight is applied to the conveyor at all times holding an almost constant tension. Even a very quick start over a 10 second period gives a 0.5 $msec^2$ acceleration rate. Note that designers may use multiple sheaves in the roping system to gain mechanical advantage, but gravity is more than up to the mark to compensate and still holds an almost constant tension.
A horizontal winch's dynamics cannot be compared to a weight tower. Unlike a weight tower, there is no assistance to move the carriage from gravity. This must be provided by the winch along with any energy to overcome stiction in sheaves and additional forces to hold tensions in a lengthening loop take up.
A condition that is unique to mining is the continual expansion and contraction of conveyor lengths.
This has led to the development of loop take up modules that can store up to 200 meters of belting. They consist of a number of transverse layers of belting operating through a series of pulleys. One pulley system is fixed, the other mounted on a rail that can be hauled by a winch. A couple of examples are shown below.



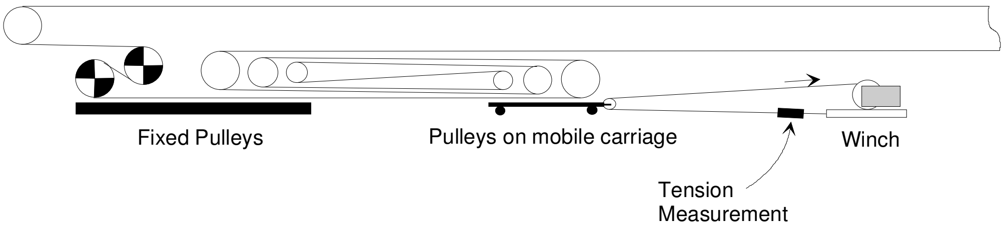


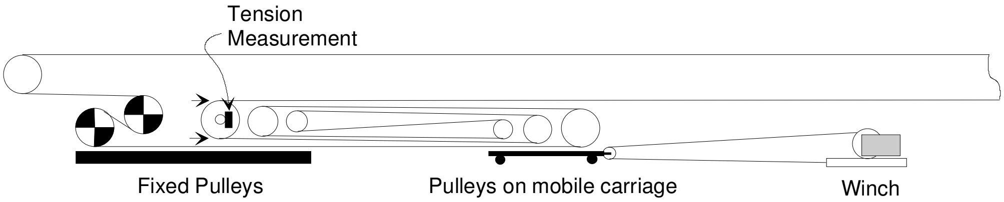
Note that each layer of belting within the loop take up is travelling in the opposite direction to the one that is adjacent to it.
An arrangement of concertinaed guide idlers (not shown in diagram for clarity) that travel up and down with the carriage are used to help prevent adjacent layers of belt from slapping together.

Unfortunately the underground winch industry has had its share of marketing myths. These have been left unchallenged due the difficulty in measuring the T2 tension. Although, the same method used for measuring tripper tension could be adapted. (Simple triangular frame and two load cells.) As this is the tension that is trying to be controlled, it is the optimum point to measure, and the point that will provide the most reactive closed loop control. Trending this point is an indication of the effectiveness of the winch's operation.



Other points, such as the end of the rope attached to the winch, or load cells under fixed pulleys do not accurately reflect the T2 tension due to stictions and moving masses between the T2 point and the point of measurement. During the belt reeling operation however, a loop tension feedback point is still required for the correct operation as the conveyor is clamped off.





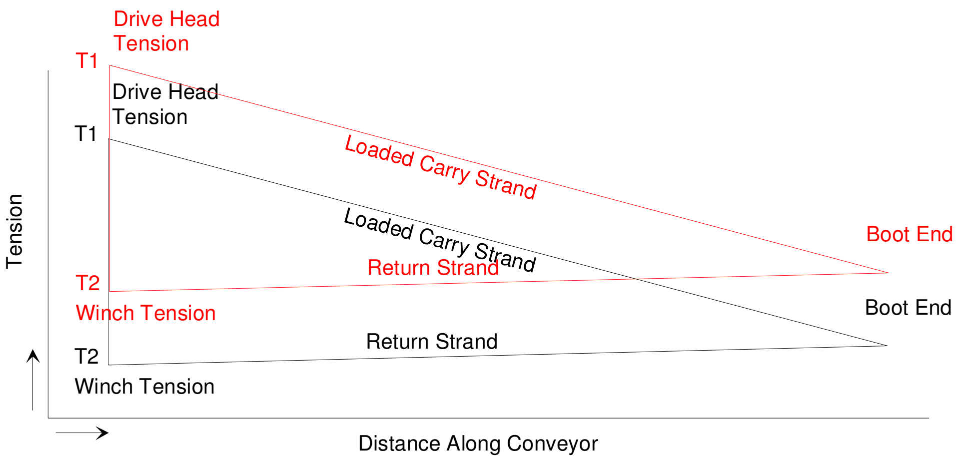
A correctly operating winch should perform the following functions :-

1. Hold the correct T2 tension in order to maintain drive pulley face pressure. This maintains friction and prevents belt slip.
2. Hold sufficient tension in the loop take up to prevent adjacent layers from slapping together. Slapping adds shock tension to the conveyor which will provide problems for closed loop control of both tension and motor current balance in the drive head.
3. Provide additional energy as required to overcome the stictions and inertia that exists in the weight of the mobile carriage and pulley system during belt length changes. The early starting period of a loaded conveyor is the most dynamic for length change as the carry strand stretches under its load.

There have been many methods of winching tried. These have included reversing drives, hydraulic pumps & motors, eddy current winches, high speed reversing drives (APW) and vector control drives. All have attempted to winch using a constant torque philosophy trying to match gravity. However energies required in a horizontal system are different from those in a vertical system.
Of the systems tried, vector winching offers the best opportunity to provide the right solution because it is the most controllable. However improved measurement and feedback may find the simpler and cheaper solutions are quite adequate.

1.4. *Winching Issues to Overcome*

To view the effectiveness of a winch, stand some distance behind the drive head and view the lower level of belt. This belt should be taught under all circumstances. Any dip or flapping indicates poor tension control.
There is a temptation to increase winch tensions and therefore drive drum face pressure when belt slip occurs. Although this may solve the immediate issue, it is not without penalty. Increasing the minimum tension in a conveyor also increases its maximum tension by the same amount. See the diagram below indicated in red.



Open loop tension control and **high hysteresis haul in / haul out** methods suffer the most for accuracy. These include fixed excitation of eddy current coils, fixed pressure hydraulic winches, fixed torque vector drive, drive head proportional torque vector drive, reversing and APW winches. The open loop methods fail to compensate for variations in roping layers and therefore the changing diameter of the winching drum. They make no allowances for stiction in sheaves and the additional energy requirements of the moving carriage inertia. The high hysteresis methods allow for large changes in T2 tension and usually interfere with the speed control of the drive head during starting.
Poor maintenance will contribute to problems in a loop take up and winch. Coal spillage onto the carriage rail system and excess water will cause problems. Sticky sheaves in the roping system and sticky carriage wheels require more torque energy to overcome and will effect winch operation and may even exceed the capacity of the winch.
Moving carriage inertia in closed loop systems is the biggest single problem for a winch to overcome. This includes the weight of the carriage and pulleys to be hauled along the rail as well as the turning inertia of the pulleys themselves when the conveyor first starts to move. Current tension measurement techniques place the carriage inertia between the T2 point and the measurement point. It therefore provides a belt tension (T2) feedback dampened by the inertia of the carriage. This leads to lower than expected T2 values during starting and belt slip. Feed forward techniques that transfer belt speed and load to the winch can be used to help the winch haul at a rate equivalent to belt speed during the initial start period where the belt is first stretching. However, belt speed monitoring is usually not very accurate at low speeds and may have built in lags with slow pulse rates used to measure speed. Here pulses from a smaller diameter, such as a strain measuring idler would be an advantage. Pulsing techniques ideally provide a pulse per second at 1% of belt speed for reasonable control.
High speed haul out in conveyors stopping. Tensions around the conveyor can change dramatically when a conveyor is stopping depending on its configuration. Once the drive motors are switched off, the inertia of the load keeps pushing forward. This action transfers the minimum tension to the drive head and the maximum tension back to the winch area via the return strand of the conveyor. There are many factors which affect the size of this tension reversal and these are resolved through dynamic modelling and analysis. Braking in front of the winch exacerbates the size of this tension. It is best to have discussions with the conveyor designer before deciding the best method for a winch to behave during stopping. Be aware that anti-runbacks in gear boxes, brakes and locked up winches can hold very high tensions in a conveyor after stopping if a tension release cycle is not deployed. Brakes supplied with winches are typically park brakes only and should not be applied unless the winch is stationary. They are designed to hold, not to brake. Using them as a decelerating brake may lead to burn out. A locked off winch will place high tensions in the loop take up during stopping and will hold higher tensions in the conveyor when it is stationary. An active winch during stopping can lead to a high speed event, when higher belt tensions cause the

lower torqued winch to wind out. This has led to tyne flaring in eddy current winches and bus overvoltage in vector winches.

The start rate of the conveyor, affects the rate at which belt is fed toward the winch. A slower starting conveyor, particularly at breakaway and before the conveyor is fully stretched, is much easier for any model of winch to adapt to, over a fast breakaway. (Except possibly the APW which was developed to thrive on fast, uncontrolled starts. e.g. delayed filled fluid couplings.) This is a function of how much tension has to be dropped at T2, in order to provide the required acceleration rate of the pulley carriage.

1.5. *Speed Control with Vector Winches*

As can be seen above, open loop control and even closed loop control of torque using a winch have many short comings when compared to a gravity tower. This is primarily due to insufficient energy being available to accelerate the pulley carriage without loss of torque from the T2 position. Speed control of T2 tension with a vector winch provides the option of using a speed reference to the winch, based on tension. A PID control with a high proportional gain using tension feed back against a tension reference and a feed forward bias based on belt stretch during starting. The output would be a speed reference to the vector winch, with the additional torque required to overcome stiction and inertias, provided automatically by the vector winch controller. With tension measured at the actual T2 position, speed feed forward would not be necessary, however given the current configuration of most loop take ups, feed forward of belt speed and belt stretch can be estimated and used to overcome pulley carriage inertia.